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WHAT FERTILIZERS FOR CROP ROTATIONS?

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FERTILIZER applications usually affect the yields of the crops to which they're applied. But exactly how much influence a given amount of fertilizer will have on the yield of even a *single* crop at a *specific* location in any *one* year is less certain.

Management and fertilization of previous crops also affect the yield of any one crop in a rotation or cropping sequence. Weather variations, too, complicate precise predictions of a crop's response to fertilizers. So most yield predictions and fertilizer recommendations are based on *average* behavior.

Let's look at some fertilization problems of a few "example" cropping sequences to get an idea of the effects of year-to-year variations and of how different crops in a sequence can affect profits from fertilizers.

Nitrogen for Corn: Table 1 shows the average optimum rates of nitrogen per acre for continuous corn at four locations in Iowa. The *optimum* rate is the one that will give the greatest profit per acre from fertilizer use.

The *ratio of prices* (fertilizer price to crop price) is what's important in determining the optimum fertilizer *rate*. The actual *price levels* determine the *amount* of return to fertilizer investment.

The nitrogen-corn price ratios in table 1 are 1:10 and 1.5:10—with the price of nitrogen at 10 cents and 15 cents per pound, respectively—and with corn at $1 per bushel. The optimum fertilizer rates at other prices for nitrogen and corn still would be the same as in table 1 as long as the nitrogen-corn price ratios remained at a 1:10 or 1.5:10 relationship.

If corn were 80 cents per bushel and nitrogen, 8 cents per pound (still a 1:10 ratio), for example, the 1:10 price ratio still determines the optimum rate to apply. If corn were $1.50 per bushel and nitrogen, 15 cents per pound, the optimum rate still should be the same as that listed in the table for 10-cent nitrogen and $1 corn. The *total return* to fertilizer investment would be less for the cheaper corn and greater for the higher-priced corn. But the same amount of nitrogen would give the *greatest* possible *return per acre* in either case.

The data in table 1 are based on results of test corn plots that were well supplied with phosphorus and potassium. Soils were limed where necessary. Adapted hybrids were planted, and insecticides were applied to control soil insects. Other soil and crop management practices were as timely as the seasons permitted.

The Bloomfield plots had the highest average optimum rates of nitrogen. Nitrogen needs of corn are high here because the soil at Bloomfield (Edina silt loam) is both low in organic matter and poorly drained. There was about a 10-pound difference between the optimum rates at Independence and at Ames—even though both tests were on fairly good corn soils. The site at Ames, however, has been in corn each year since 1915. The lowest optimum rates were at Kanawha, where the moisture supply was limited in at least half of the years of the test period.

The difference in optimum application rates because of change in nitrogen price also averaged highest at Bloomfield. The difference during the 9 years averaged 19 pounds of nitrogen per acre, valued at $2.85. The greatest difference was 25 pounds of nitrogen per acre between the 1:10 and 1.5:10 price ratios in 1952.

At the other sites, average nitrogen rates differed by 10 pounds per acre or less between the 1:10

TABLE 1. Optimum nitrogen rates for continuous corn at four locations in Iowa with corn at $1 per bushel, 1952-60.

		Experimental farm and location			
Nitrogen price/lb.	N:corn price ratio	Carrington-Clyde, Independence	Agronomy, Ames	Clarion-Webster, Kanawha	Southern Iowa, Bloomfield
		Average pounds nitrogen per acre			
10c	1:10	116	126	97	173
15c	1.5:10	106	117	93	156

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and 1.5:10 price ratios. In individual years, the rate difference varied as much as 15 pounds of nitrogen per acre between the two price ratios.

Not all is lost if you do over-fertilize because of fertilizer price changes or price uncertainty. Consider a hypothetical example for the Carrington-Clyde experiment. In 1953, the optimum nitrogen rate was 125 pounds per acre for the 1:10 price ratio and 110 pounds for the 1.5:10 price ratio —a difference of 15 pounds. If 125 pounds per acre of nitrogen had been applied at an expected cost of 10 cents per pound, but the actual price was 15 cents, an extra $2.25 per acre would have been spent. The extra 15 pounds of nitrogen, however, would have produced 1.9 extra bushels of corn per acre. With corn worth $1 per bushel, the actual drop in return to fertilizer investment because of over-fertilization would have been only 35 cents per acre rather than $2.25.

What if a more likely situation occurred—such as a drop in the price of corn? Suppose it dropped to 67 cents per bushel. At that price, the optimum nitrogen rate would have been 110 pounds per acre. But say that 125 pounds per acre of nitrogen at 10 cents per pound had been applied before the price of corn dropped. In this case, 15 pounds of excess nitrogen, costing $1.50 per acre, would have been applied. This additional nitrogen would have produced an extra 1.9 bushels of corn per acre worth $1.27. So the actual reduction in return to fertilizer investment because of over-fertilization would have been only 23 cents per acre.

The most serious consequence of over-fertilization is that the extra money spent for fertilizer can't be put to work elsewhere. If some corn isn't fertilized because other areas are over-fertilized, the reduction in the possible return to fertilizer improvement would be greater — because of the *lack* of fertilization of some corn rather than because of over-fertilization of the other. This comes from the fact that the first $2 per acre spent for nitrogen that was applied at any of the locations in table 1 returned $4-$5 in additional corn yields.

Year-to-Year Changes: What are the consequences of not being able to predict year-to-year yield responses to fertilizer?

When no fertilizer was applied at the Carrington-Clyde experiment, for instance, corn yields varied from 37 bushels per acre in 1958 to 79 bushels in 1957, and averaged 57 bushels during 1952-60 (see table 2).

Had it been possible to predict the optimum fertilizer rates each year, nitrogen rates would have varied from 90 pounds in 1956 (a dry year) to 160 pounds in 1960. Yield response of corn to the optimum fertilizer rate would have ranged from 22 bushels per acre in 1952 to 93 bushels in 1959, for an average of 47 bushels during 1952-60. (Yield response is the additional yield resulting from fertilization compared with yields without fertilization.) Return to fertilizer investment would have varied from $13 to $78 during the 9 years, averaging $35 per acre.

What if the 9-year *average optimum* rate of 116 pounds of nitrogen at 10 cents per pound had been applied each year?

At the 116-pound rate, an excess of nitrogen would have been applied in 6 years. But notice that the *response* to this constant amount applied each year ranged from 24 bushels of corn per acre in 1952 to 82 bushels in 1959. Return to fertilizer investment varied from $12 to $71 for those years.

Total return for the 9 years would have been $318 per acre if the *annual* optimum nitrogen rate for each year had been applied. Total return during the 9 years for the *average* optimum rate was $294. This $24 difference for the 9 years was the price paid for not being able to predict the best rate for each year.

For individual years, the difference in return between the annual optimum rate each year and the average optimum rate ranged from about $1 per acre in 6 of the years to $10 in 1960. The difference averaged $3 per acre annually in favor of the optimum rate each year during the 9 years. In 7 years, however, the difference was $2 per acre or less.

The conditions existing *before* nitrogen is applied may alter the optimum rate. Less fertilizer can be used profitably with low numbers of plants per acre. Limited subsoil moisture also may limit a

TABLE 2. Yields of unfertilized and fertilized corn, optimum nitrogen rates and return to fertilizer investment, Carrington-Clyde Experimental Farm, Independence, 1952-60.[a]

Year	Yields without fertilizer (bushels)	If ANNUAL optimum rate were applied each year				If AVERAGE optimum rate[b] were applied each year	
		Pounds N per acre	Cost of N per acre	Bushels extra corn	Profit	Bushels extra corn	Profit
1952	67	94	$ 9	22	$13	24	$12
1953	60	125	13	38	25	36	24
1954	71	110	11	46	35	46	34
1955	47	101	10	32	22	33	21
1956	65	90	9	25	16	26	14
1957	79	102	10	35	25	36	24
1958	37	106	11	75	64	75	63
1959	38	153	15	93	78	82	71
1960	49	160	16	56	40	41	30
Average	57	116	12	47	35	—	—

[a]Based on N at 10c per lb. and corn at $1 per bu. (a 1:10 price ratio).
[b]116 lbs. N applied each year.

crop's response to fertilizer. Adequate soil moisture, rainfall and high plant stands, on the other hand, tend to make heavier fertilizer rates more profitable.

Phosphorus, Potassium: Optimum rates of P_2O_5 and K_2O were estimated from C-O-M (corn-oats-meadow) rotations on Cresco silt loam and Clyde silty clay loam soils at the Howard County Experimental Farm (see table 3).

Considering each group separately, there was a difference in the rate *and* ratio of P_2O_5 to K_2O between soils and among crops or crop combinations. In the total C-O-M cropping sequence—where there's some direct and indirect effect of fertilizer carried over from applications to previous crops — corn required about 25 pounds of P_2O_5 per acre on both the Cresco and Clyde soils. The K_2O requirement was 25 pounds on Cresco but 31 pounds on the Clyde soil, possibly because of its poorer drainage.

Oats and hay considered together required about the same level of P_2O_5 on both soils. For the total rotation, P_2O_5 needs were nearly the same on both soils, but the K_2O needs were higher on Clyde soil.

The optimum fertilization rate for corn was about half of that for oats and hay together, or about a third of the rate needed for the total rotation in these tests and for the prices assumed. Prices assumed were: corn, $1 per bushel; oats, 60 cents per bushel; hay, $20 per ton; P_2O_5, 10 cents per pound; and K_2O, 5 cents.

Corn yields showed the highest gross value per acre on both soils, followed by hay and oats. For highest return to fertilizer investment, oats required more phosphorus and less potassium than did corn; hay required more of both.

Optimum fertilizer rates for corn cost $3.65 and $4.05 per acre on the Cresco and Clyde soils, respectively. These rates produced $20.60 and $34.30 worth of extra corn on the two soils, respectively, for fertilizer profits of $16.95 and $30.25 per acre.

Optimum fertilizer rates for oats cost $3.50 and $4.25 per acre on the Cresco and Clyde soils, respectively, for net returns to fertilizer of $3.68 and $2.49 per acre.

The returns from fertilizing hay compared favorably with those from corn. On the Cresco soil, $7.83 worth of fertilizer added $23.60 to the gross value of hay produced, for a net return from fertilizer of $15.77 per acre. On the Clyde soil, $9.85 worth of fertilizer added $24.60 to the gross value of hay produced, for a net return of $14.75 per acre. Remember that some oats had been produced to help defray the costs of fertilizing the hay crop. Since the return to fertilizer from oats was small compared with that from hay, the annual return per acre for the oats-hay combination was only a little more than half of that for hay alone. In practice, hay is at least a 2-year crop, and its response to fertilization must be spread over both the seeding and harvest years.

Judging from other tests, about one-fourth of the phosphorus, at the rate used, would still have been effective 2 years after application. On this basis, the optimum corn yields were produced from 35-40 pounds of P_2O_5 (when the residual effect of previously applied fertilizer is considered) rather than from the 25 pounds indicated. The oats and hay probably removed all of the potassium, however. So the potassium rate applied to corn was close to that actually needed under the conditions of the experiment.

The low amounts of fertilizer applied to corn probably would have relatively little effect on the crops following, though there would be some carryover. Thus, the total effective amount of fertilizer—because of carryover—actually available to the oats and hay following corn would be only slightly higher than the amount applied to the oats and hay.

Management: The kind of management used affects returns to fertilizer investment as well as optimum fertilizer rates. Stand level (plant population) and hybrid variety are two factors that demonstrate the influence of management. The importance of good stands in getting high responses to nitrogen is shown in table 4.

Without added nitrogen, increasing corn stands has resulted in lowered yields. With nitrogen added, however, there usually is a decided advantage in increasing plant populations. The data show that, in average years under the test conditions, it's possible to obtain highest yields with 16,000 plants per acre. In the drouth years of 1954 and 1955, 8,000 plants were enough. What was lost in yields by higher stands in those years, however, has been more than made up.

If response to nitrogen depends on plant stand, what fertilization rate is best? Again, consider nitrogen at 15 cents per pound and corn at $1 per bushel. With 8,000 plants per acre, 15 pounds of nitrogen per acre was the average rate that gave the greatest return to fertilizer investment. As the stand was increased to 12,000 plants per acre, the optimum nitrogen rates were 33 and 29 pounds per acre for A.E.S. 801 and Iowa 4297, respectively. With a stand of 16,000 plants per acre, the average optimum nitrogen rates were 59 and 46 pounds, respectively, for the two varieties. Fertilizer returns also increased at the higher stands and higher nitrogen levels.

The average optimum rates for this test were low because there was no response to nitrogen in 2

TABLE 3. Optimum rates of phosphorus and potassium fertilizer, corn-oats-meadow rotation, Howard County, 1945-59.

	Cresco silt loam		Clyde silty clay loam	
Crop	P_2O_5 (lbs./A.)	K_2O (lbs./A.)	P_2O_5 (lbs./A.)	K_2O (lbs./A.)
Corn alone	24	25	25	31
Oats alone	35	none	29	27
Hay alone[a]	48	—[b]	58	81
Oats and hay	51	—[b]	53	62
Total C-O-M rotation	74	84	78	93

[a]Fertilizer for hay applied the previous year to oats.
[b]Optimum rate was not determined.

TABLE 4. Effect of nitrogen and stand levels on yields of continuous corn, Seymour silt loam soil, Wayne County, 1953-60.

No. stalks per A.[a]	Pounds N applied per acre		
	0	80[b]	160[b]
	Average yields in bushels per acre		
A.E.S. 801 (full season variety)			
8,000	49	59	61
12,000	47	64	68
16,000	45	72	78
20,000	41	69	74
Iowa 4297 (early variety)			
8,000	48	57	58
12,000	47	63	65
16,000	43	72	72
20,000	36	67	72

[a]8,000 = 2 stalks every 40 inches; 12,000 = 3 stalks every 40 inches; 16,000 = 2 stalks every 20 inches; 20,000 = alternating 2 and 3 stalks every 20 inches all in 40-inch rows.
[b]Nitrogen applied each year except 1955, which followed a very dry year.

drouth years during the test period of 1953-60. The drouth was anticipated in both years, because the subsoil moisture at planting time was extremely low. (Under such conditions, you'd probably withhold nitrogen until you were more sure of favorable moisture prospects.) In 1960, a good corn year, the optimum nitrogen rate was 117 pounds per acre for 16,000 plants of A.E.S. 801 per acre, with 15-cent nitrogen and $1 corn. This rate compares closely with the rates shown in table 1.

Application Timing: Certain crops in a rotation respond more to fertilizer and are more profitable than others. If the amount of money available to spend for fertilizer is limited, there may be some advantage in carefully choosing the fertilizer *and* the crop to fertilize.

Consider, for example, only the phosphorus for oats and corn of a corn-oats-meadow-meadow rotation during 1950-59 on Ida silt loam soil in Monona County. Assume that the phosphorus was applied to the oat-legume seeding. Use the same prices as before: oats, 60 cents per bushel; corn, $1 per bushel; P_2O_5, 10 cents per pound.

The optimum rate of phosphorus—if only the yield of oats is considered—is 95 pounds of P_2O_5 per acre. The oat yield increase would be worth $15.60, for an immediate fertilizer return of $6.10 per acre. Some of the phosphorus would stay in the soil. It would directly or indirectly contribute to a corn yield increase 3 years later valued at $26.90 per acre. The total return from the phosphorus would be $33 for the two grain crops in the rotation. Hay yield increases would add to this return.

Thinking about the optimum rate of phosphorus for the corn crop coming 3 years after the oats, it would be necessary to apply 256 pounds of P_2O_5 to the oats. This rate would cost $25.60 per acre and would give a corn yield increase worth $54 per acre, for a return to the phosphorus investment of $28.40 per acre from corn. The increased yield of oats from the phosphorus would be worth $14.15 per acre. The total return to phosphorus investment for the two grain crops in the rotation would be $42.55—about 30 percent greater than when only the optimum for oats was considered.

Suppose you're willing to wait until you harvest the corn crop for the profit from fertilizer but want to break even the first year on fertilizer costs. In this case, you would apply 189 pounds of P_2O_5 per acre to the oats. The additional oat yield would just pay for the phosphorus. The increase in corn yield would return $45.94 per acre to the phosphorus investment.

To get the greatest return to phosphorus investment on the corn and oats taken together would require 204 pounds of P_2O_5 per acre, worth $20.40. The increase in grain yield of the oats and corn together would result in a return of $46.19 per acre from the phosphorus.

Other Factors: Continuous corn commonly requires more than 100 pounds of nitrogen to produce optimum yields. On most of the soils included in table 1, first-year corn following a legume meadow requires no additional nitrogen. When corn is grown in a rotation with a legume meadow, the meadow furnishes some nitrogen for the corn crop.

Meadow crops can furnish *only* nitrogen to the soil. They use as much as or more phosphorus and potassium than does corn. A 70-bushel corn crop harvested for grain, for example, contains about 10 pounds of phosphorus and 13 pounds of potassium. A 3-ton alfalfa hay crop removes about 14 pounds of phosphorus and 123 pounds of potassium. Including a meadow crop in the rotation reduces the nitrogen fertilizer needs, but the need for other nutrients may be increased. (See "Crop Rotations—Facts and Fiction" in the March 1962 issue or reprint FS-954.)

Total quantities of potassium are very high in most soils, but potassium is released too slowly in some soils for best plant growth. Yields may be increased from such soils by adding potassium fertilizer. Legumes may show greater response to potassium than does corn. But higher returns to fertilizer investment are more likely with corn than with meadow. This is because it's usually more profitable to fertilize corn at rates high enough for the optimum yield.

The carryover effects of fertilizers also must be considered. Forty to 60 percent of a P_2O_5 application will carry over to the next year. If cornstalks or oat straw aren't removed, K_2O carryover to the next year after application may be as high as 60-90 percent. Little K_2O will carry over if the meadow is cut for hay or if all the corn or oats residue is removed.

Your capital situation and your goals will influence your cropping systems and your fertilization practices. Your capital position, for example, may help determine the fertilizer rates and the crops to fertilize. Adjust fertilizer rates in anticipation of certain weather possibilities, but still expect year-to-year weather fluctuations.